EÖTVÖS LORÁND UNIVERSITY

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ELECTROPHYSIOLOGICAL CORRELATES OF THE ATTENTION-DISTRACTION BALANCE

– **PhD thesis booklet** –

DOCTORAL SCHOOL OF PSYCHOLOGY

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1 INTRODUCTION AND GENERAL BACKGROUND

In order to adapt and react to our constantly and dynamically changing environment, is crucial to select which events to attend to and which ones to ignore. However, it is impossible to reach such a perfect attention set because salient, unexpected external events capture our attention, in other words, we get distracted. For example, imagine that you are absorbed in reading a highly interesting book and try to ignore all the ambient noises like the neighborhood or the traffic in the street. But suddenly, the fire alarm is starting with loud, salient sounds, capturing your attention, that is, distracting you. Along with distraction, the sound of fire alarm also motivates you to evaluate the situation: does it worth more to continue reading or rather to change your behavior and leave the room (see Fig. 1.1).

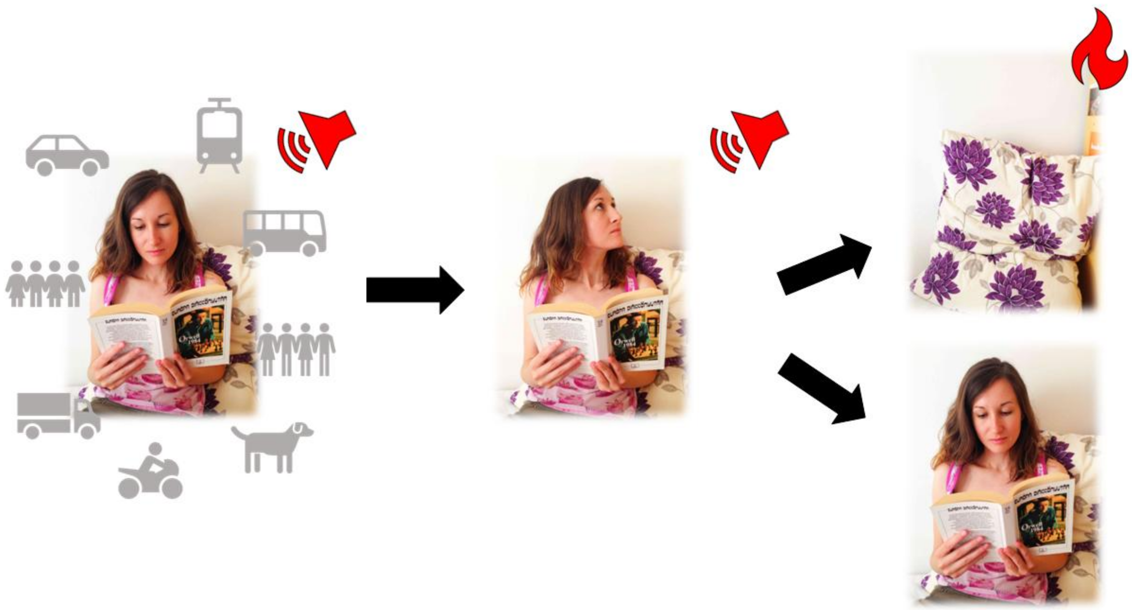

Fig. 1.1 A typical everyday scenario illustrating the attention-distraction balance. Rare, unexpected acoustic events from the environment capture one's attention, that is, they distract us.

Because such scenarios are too complex to be investigated in laboratory context, experiments in cognitive psychology aim to model them utilizing more basic stimulation. A widely used paradigm to investigate distraction is the modified version of the oddball paradigm in which rare (10-20%) sensory events, (*deviants*) unexpectedly break the regularity built-up by frequently presented stimuli (termed *standards*). The auditory version of the paradigm was introduced by Schröger and Wolff (1998b) who presented short and long (100 and 200 ms) tones with 50-50% probability. The pitch of the tones changed occasionally (deviants) and participants had to perform a duration discrimination task while ignoring pitch. The occurrence of such deviants typically lead to numerous changes both in behavior and electrophysiological (event-related potentials – ERPs) aspects. First, participants typically respond slower and less accurate to these events. Second, the co-called "distraction potential" arises at fronto-central areas when subtracting ERPs to standards from deviants, consisting of three deflections. The mismatch negativity (MMN) around 100-250 ms is usually thought as an index of acoustic change detection and violation of regularity and predictions (Alho, 1992; Näätänen, 1982; Winkler & Schröger, 2015). MMN is followed by a positive deflection (P3a) between 250-400 ms which is related to orientation of attention (Escera & Corral, 2003) and task-relevance (Dien, Spencer & Donchin, 2004). Finally, attention needs to be oriented back to the task, which is indexed by the re-orientation negativity (RON) between 400 and 600 ms (Schröger & Wolff, 1998a).

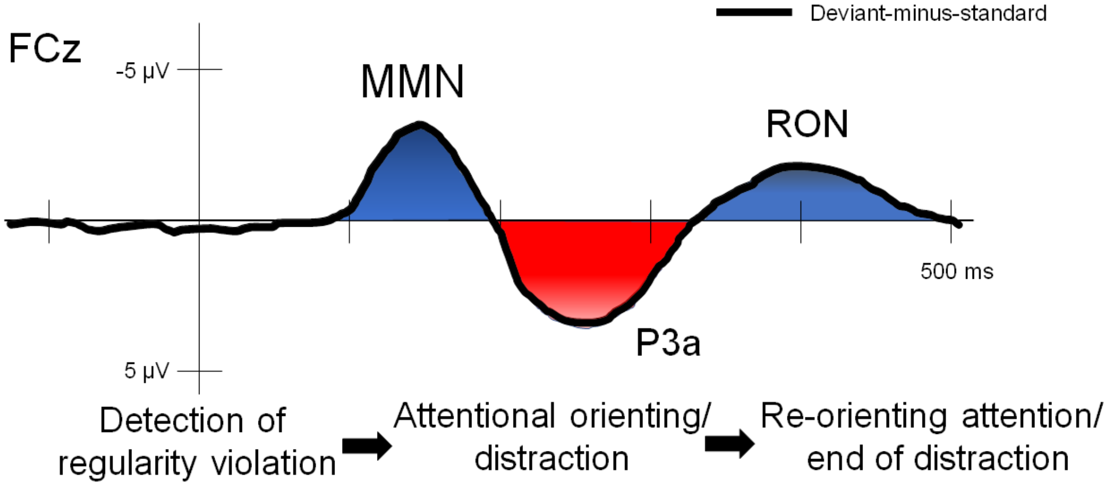

Fig. 1.2 Schematic design of the distraction potential at FCz electrode. The different deflections index the stages of distraction: MMN indices violation detection, P3a reflects the orientation of attention or distraction, and RON is supposed to be elicited by the re-orientation of attention.

Predictions play a crucial role in the dynamics of this balance. If we know what types of stimulus events may occur, we can establish selective attention sets, enabling to prepare for task-relevant sensory events while ignoring task-irrelevant ones (e. g. Parmentier, 2014). In studies utilizing oddball tasks, predictability is often provided by visual cues presented preceding every tone, indicating whether the forthcoming stimulus will be standard or deviant. When such cues predicted with at least 80% accuracy the type of the forthcoming tone, behavioral and electrophysiological (P3a, RON amplitudes) correlates decreased significantly (Horváth & Bendixen, 2012; Horváth, Sussman, Winkler & Schröger, 2011; Horváth, Winkler & Bendixen, 2008; Sussman, Winkler & Schröger, 2003; Wetzel, Widmann & Schröger, 2009). However, because the presentation times between cues and target tones are rather short (340-900 ms), it is ambiguous whether the reduced ERP amplitudes result from preparation or they are rather a byproduct of the processing of the previously presented cues.

We can also make use of cues that predict *when* task-relevant events can occur and prepare for their processing at a given moment in time (Holender & Bertelson, 1965). Interestingly, several recent studies utilizing oddball tasks found abolished or even reversed behavioral effects to distracters (Li, Parmentier & Zhang, 2013; Parmentier, Elsley & Ljungberg, 2010; SanMiguel, Linden & Escera, 2010; SanMiguel, Morgan, Klein, Linden & Escera, 2010; Wetzel, Widmann & Schröger, 2012), which can be explained with the temporal regularities of the presentation: in these studies, irrelevant and relevant events were presented with constant temporal separation, typically in the range of 100-200 ms (e.g. Berti & Schröger, 2001; Schröger & Wolff, 1998a, 1998b; Wetzel, Widmann & Schröger, 2012), but even as high as 600 ms in some experiments (Ruhnau, Wetzel, Widmann & Schröger, 2010). Because of this, it seems reasonable to assume that task-irrelevant events play a "supportive" role in performing the task by allowing temporal preparation for the forthcoming task-relevant event. However, the hypothesis whether task-irrelevant distracters can act as temporal cues was not tested yet directly.

This balance between attention and distraction is often described to be shifted in older adults: numerous studies suggest that older adults are more susceptible to get distracted because they are less able to suppress task-irrelevant sensory events (Hasher, Lustig & Zacks, 2007) and that a general motor and cognitive slowing is also present (Salthouse, 1996). Based on this, one might hypothesize that the distracted state also persists longer in their case. However, results of studies utilizing oddball paradigm and distracter potential are mixed: although reaction times are usually slower or similar to younger adults, amplitudes of different ERP (MMN-P3a-RON) components tend to be similar or smaller (but sometimes larger) compared to younger adults; and latencies either delay or do not differ from the younger adults' (Amenedo & Díaz, 1998; Berti, Grunwald & Schröger, 2013; Gaeta, Friedman, Ritter &

Cheng, 1998; Getzman, Gajewski & Falkenstein, 2013; Horváth et al., 2009; Iragui, Kutas, Mitchiner & Hillyard, 1993; Mager et al., 2005) which may reflect differences between the utilized tasks but also between individuals. Because of the inconsistencies in results utilizing "distraction potential" with aging, our aim was to utilize a more unambiguous method to follow-up the time course of the orientation of attention.

The method we applied in studies with older adults was based on the results which suggest that different stages of attention can be followed-up utilizing the amplitude modulation pattern of N1 component (Schröger, 1996). N1 is a negative going waveform peaking around 100 ms and similarly to MMN, it is thought to reflect sensory change detection (Näätänen & Picton, 1987). N1 is elicited with enhanced amplitudes when a stimulus in the focus of attention (Alho, 1992) while attentional disruptions lead to its attenuation (Horváth, 2014), for a typical modulation pattern see Fig. 1.3. When participants attended to the tones and performed a task with them, acoustic target events separated from rare, task-irrelevant changes in 150 and 200 ms led to smaller N1 amplitudes compared to such events separated in 560 or 650 ms (Horváth, 2014; Schröger, 1996). In contrast, when acoustic simulation was presented in the background and was ignored, brief separations from the distracting event resulted in N1 enhancement (Horváth & Winkler, 2010). Therefore, we supposed that the amplitude modulation of N1 probed at different timepoints following a deviant auditory event might reflect more directly the duration of impact of rare event (that is, distraction) and allows a more straightforward comparison between age groups. We hypothesized that the modulation of N1 amplitude – indicating distracted state – will last longer in older than in younger adults.

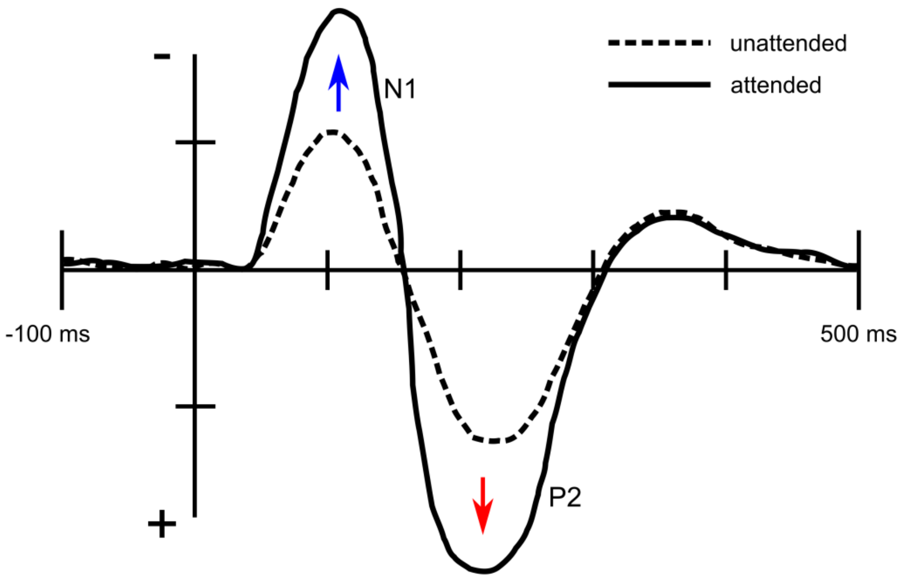

Fig. 1.3 Modulation of the N1 (and P2) amplitudes with attention.

The aim of the present dissertation was to investigate the role of predictability in prevention of distraction and in cue utilization as reflected by the distraction potential and behavioral indices. Besides, we compared older and younger adults in terms of the duration of the distracted state by manipulating the temporal separation between distracter and target events and utilizing the modulation pattern of N1 sensory ERP.

Based on the studies described above we formed the following hypotheses:

- When information on the occurrence of the forthcoming deviant is presented continuously instead of preceding cues, distraction effects will be reduced.
- When otherwise task-irrelevant, distracter events carry information on the presentation time of the forthcoming task-relevant stimuli, these distracters will be regarded as temporal cues and will be included into the task set.
- The duration of the distracted state will last longer in older adults compared to the younger ones, both in task situations and during passive listening.

2 THESES

2.1 Providing continuous information on the presentation of the forthcoming deviant reduces distraction[1]

Thesis I. When information on the occurrence of the deviant is not delivered by cues preceding every tone but in a continuous way, distraction effect is diminished as reflected by reduced P3a amplitudes.

2.1.1 Methods

14 healthy younger adults participated in the experiment (9 women, aged: 19-26 years, mean age: 22 years). They listened to 643 ms long discrete tones starting in the middle and moving from the center either to the left or to the right after 184 ms and the task was to respond to the direction of the movement while ignoring frequency. The stimulus-onset-interval (SOA) between tones was 1300 ms. In the predictable condition, every 7th tone was pitch-deviant, while in the random condition the position of deviants was random with probability of 1/7. Moreover, in order to minimize the effort needed to keep the current position within the sequence in mind to be able to prepare for forthcoming deviants, a visual counter showing the sequence position was presented as a constant reminder, which made information on forthcoming tones continuously available throughout the experimental blocks of the predictable condition. That is, for each participant, deviant tones always occurred at a certain transition of the counter while in the random condition no relationship was present between the position of the counter and the type of the presented tone (see Fig. 2.1). We hypothesized that such knowledge about the stimulus sequence would reduce or abolish behavioral and ERP effects of distraction.

[1] Study I: **Volosin, M.**, & Horváth, J. (2014). Knowledge of sequence structure prevents auditory distraction: An ERP study. *International Journal of Psychophysiology, 92,* 93-98.

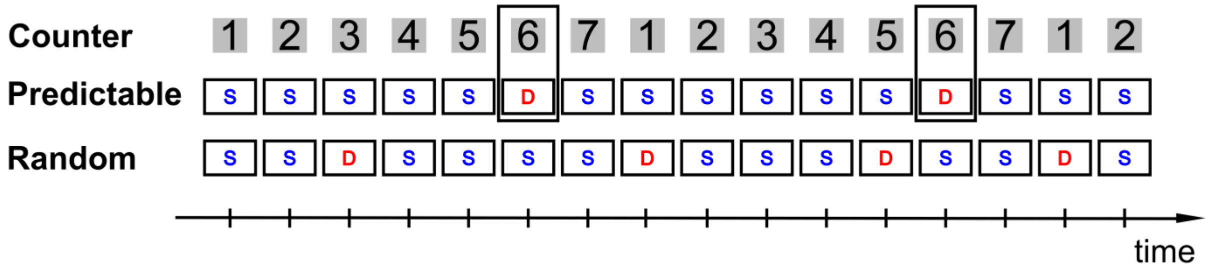

Fig. 2.1 Schematic design of Study I. In this example, deviant (D) occurs always when the counter switches from 5 to 6 in the predictable condition, while in the random condition the position of the counter does not predict the occurrence of the deviant tone.

2.1.2 Results

Behavior was characterized with reaction times and d's and distraction-related ERPs were analyzed (MMN, P3a). Participants performed with similar response speed and accuracy to standards and deviants, irrespectively whether it was predictable or random. Whereas the early ERP correlates of deviance-processing (N1, MMN) were unaffected by predictability, P3a amplitude was significantly reduced in the predictable condition, indicating that prevention of distraction was based on the knowledge about the temporal structure of the stimulus sequence, and not processing interference.

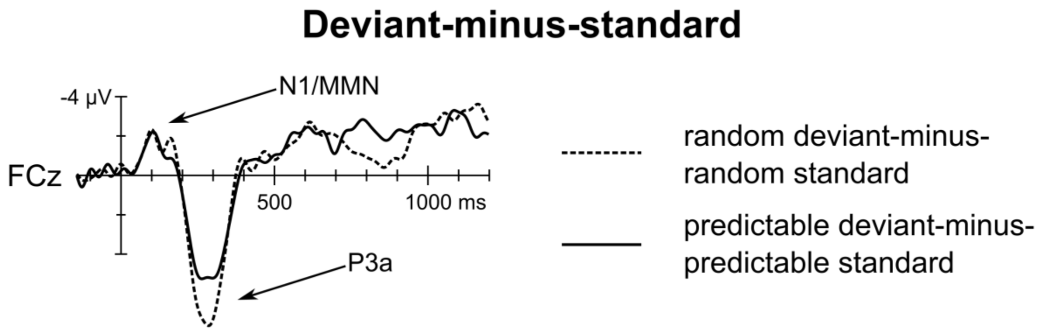

Fig. 2.2 Group-average (N=14) deviant-minus-standard waveforms in the random and the predictable conditions. While predictability did not affect MMN, P3a elicited with significantly lower amplitudes in the predictable condition.

2.2 Exploiting and utilizing temporal regularities from otherwise task-irrelevant stimuli[2]

Thesis II: When distracter and task-relevant auditory events are separated by a constant time interval, distracter events are regarded as temporal cues by the auditory processing system and they are utilized during the task.

2.2.1 Methods

14 young adults (mean age: 23, from 19 to 31 years, 12 women) participated in the experiment. Instead of discrete stimuli, continuous tones featuring short (10 ms) and long (100 ms) gaps were presented, alternating between two frequencies by quick glissandos (glides) (see Fig. 2.3). Participants performed a gap duration discrimination task, while ignoring glides. Glides could be presented frequently or rarely. In the informative condition, 80% of the glides predicted the presentation time of the forthcoming gap (400 ms), while in the uninformative condition, the occurrence of gaps and glides was independent. We hypothesized that in the informative conditions glide-related ERPs will feature an enhanced N1 (possibly involving PN or Nd) due to the establishment of a selective attention set for the glide, and that the glide will be followed by a contingent negative variation (CNV) reflecting preparation for the forthcoming gap. It was further hypothesized that the rare-minus-frequent glide difference waveforms would show the characteristic distraction waveform: MMN and P3a. Importantly, we hypothesized that the cue value of the glides would modulate the rare-minus-frequent glide difference waveforms: informative glides would lead to the emergence of an N2b, and the enhancement of the P3a in the difference waveform. Conversely, if cue utilization would be interrupted by distraction, the CNV would be elicited with lower amplitude in the informative rare glides condition than in the informative frequent glide condition.

[2] Study II: **Volosin, M.**, Grimm, S., & Horváth, J. (2016). Exploiting temporal predictability: Event-related potential correlates of task-supportive temporal cue processing in auditory distraction. *Brain Research, 1639*, 120-131.

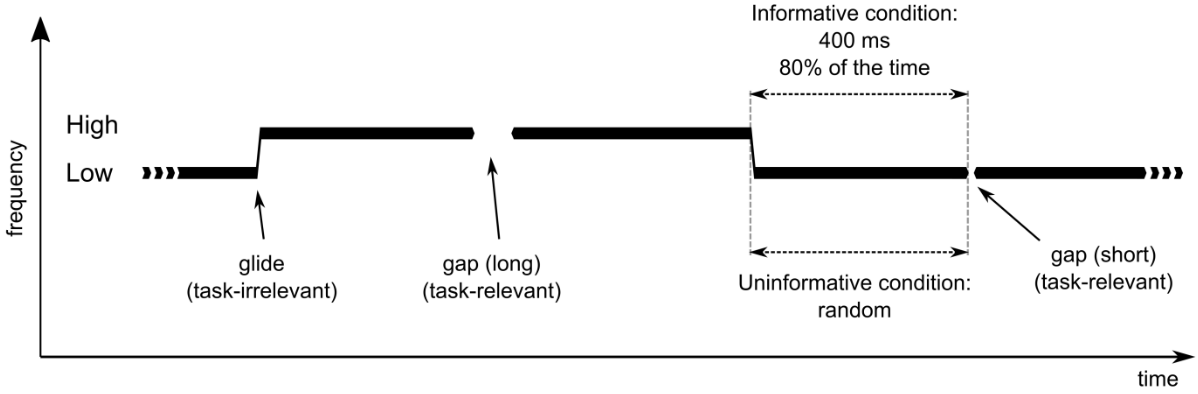

Fig. 2.3 Schematic design of the experimental paradigm in Study II, including glides, short gaps and long gaps. The thick black line represents the continuous tone alternating between two pitches (non-target glides) and the short breaks mark the gaps (short and long targets). The difference between glide – gap time intervals and the predictive values in the informative and uninformative conditions are marked with dashed lines.

2.2.2 Results

Behavior was characterized with reaction times and d's and we found that informative glides led to faster responses but did not affect the accuracy of gap duration discrimination. Regarding electrophysiology, we identified ERP components to glides reflecting processes related to distraction (MMN, P3a) and preparation (CNV). Although the cue function of glides did not affect the P3 amplitudes, N2b was elicited by the rare informative glides, and CNV was elicited in both informative glide conditions (Fig. 2.4). These results suggest that participants included the informative glides into their task-behavior, that is, they utilized the distracter glides as temporal cues.

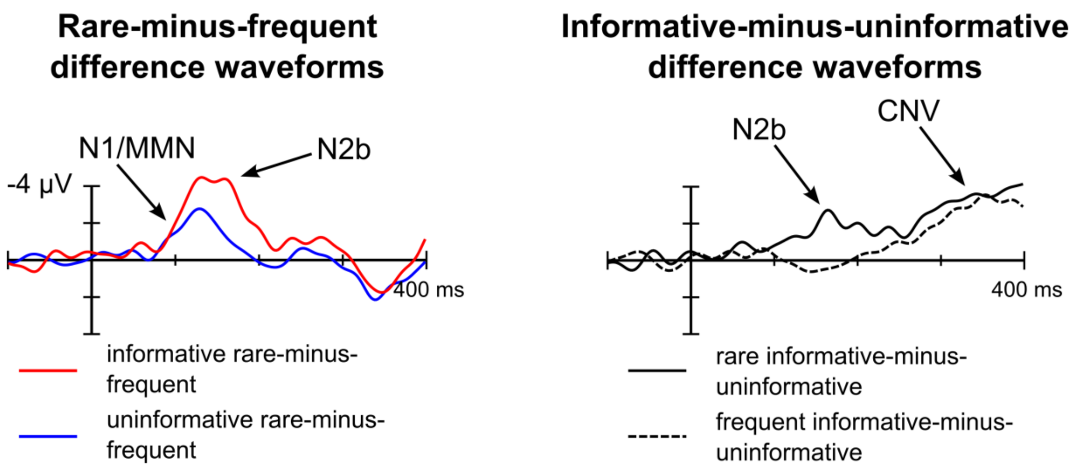

Fig 2.4 Group-average (N=14) glide-related rare-minus-frequent and informative-minus-uninformative difference waveforms, showing the foreperiod effect.

2.3 Comparing the duration of impact of distracter stimuli between younger and older adults in attended task situation[3]

Thesis III: Although the distracted state seemingly does not last longer in older than in younger adults, older adults might utilize compensational strategies and enhanced attention.

2.3.1 Methods

The data of 16 younger (age: from 19 to 26; mean: 22.6 years) and 16 older (age: from 62 to 74 years, mean: 67.3 years) adults was utilized in the present study. They listened to continuous tones containing rare pitch changes (glides) and short gaps. Glides and gaps could be separated in 150 ms, 250 ms, 650 ms or longer and the task was gap detection while ignoring glides (see Fig. 2.5). We hypothesized that shorter glide-gap separations would lead to stronger N1 amplitude reductions because the optimal attention set for detecting a gap could not be fully restored after distraction occurred. We also hypothesized that in older adults, the effects of distraction – manifested in lower N1 amplitudes to gaps – would persist longer.

[3] Study III: **Volosin, M.**, Gaál Zs. A., & Horváth, J. (2017a). Task-optimal auditory attention set restored as fast in older as in younger adults after distraction. *Biological Psychology, 126,* 71-81.

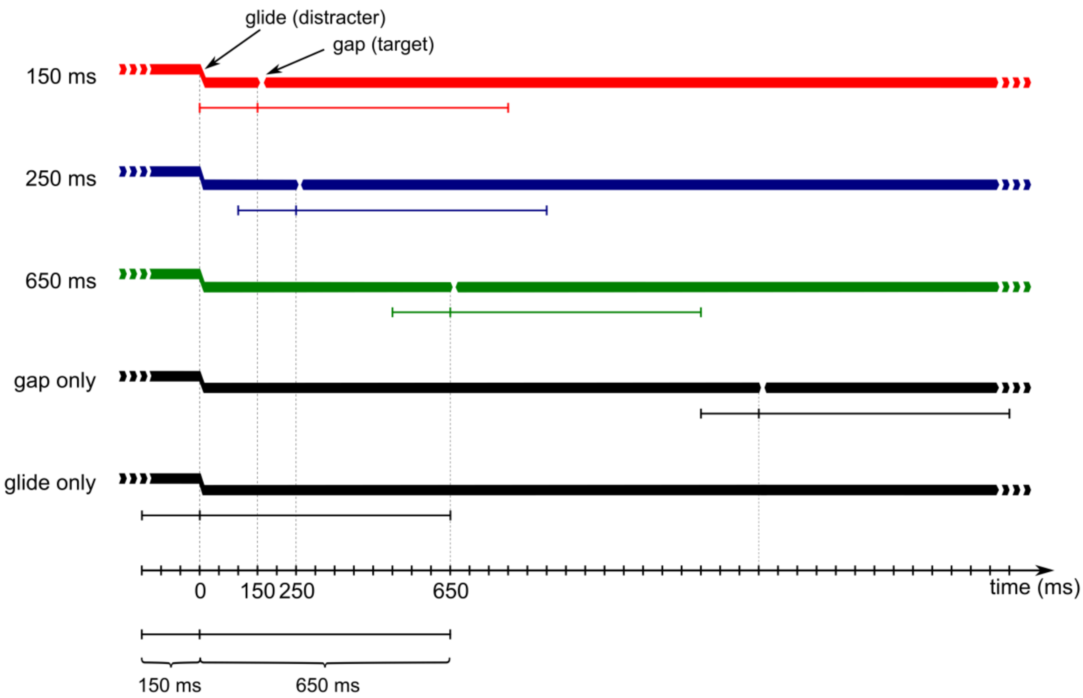

Fig. 2.5 Schematic design of the experimental tones reflecting glide-gap separation intervals and epoch types. The different colors represent the different glide-gap separations in the continuous tone.

2.3.2 Results

With longer glide-gap separations similar N1 enhancements were observable in both groups suggesting that the duration of the distracted sensory state was not affected by aging. Older adults responded, however, slower at short glide-gap separations in parallel with high accuracy, which indicated that distraction at subsequent levels of processing may have nonetheless more impact in older than in younger adults.

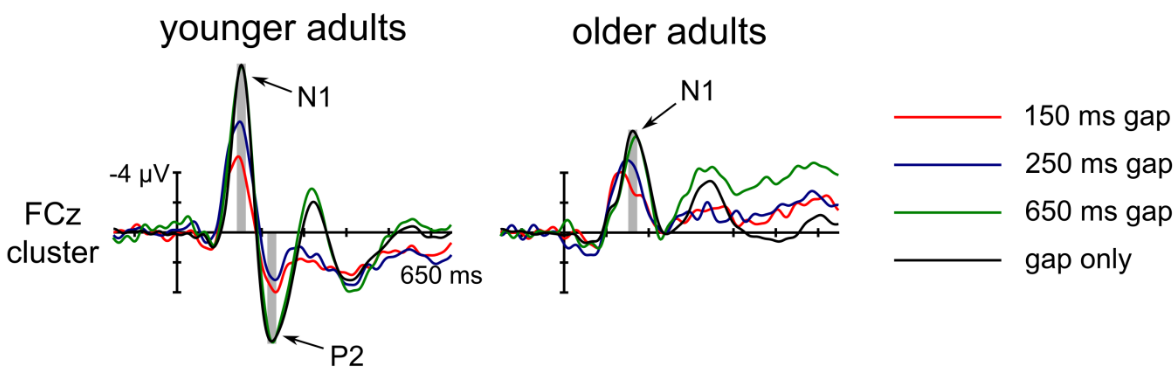

Fig 2.6 Group-average (younger adults: n=16, older adults: n=16) ERP results of the study. Gap-related ERPs are plotted at the a cluster around FCz electrode for younger and older adults separately. The grey bands index the time windows where statistical analyses were assessed.

2.4 Comparing the duration of impact of distracter stimuli between younger and older adults while ignored background auditory stimulation[4]

Thesis IV: Although the impact of the rare auditory events in the background stimulation does not last longer in older than in younger adults, the processing of the fine temporal resolution is deteriorated in older adults.

2.4.1 Methods

The final sample of the present study consisted of 23 younger and 23 older adults. The average age was 22.13 years (SD = 2.01; from 18 to 26 years) in the younger and 68 years (SD = 3.71; from 62 to 76 years) in the older adult group. Participants were watching a silent movie with subtitles while ignoring auditory presentation in the background which was characterized with the same structure as in the study presented in Thesis III (see Fig. 2.5). We hypothesized a reversed pattern of N1 modulation than during active task presented in Thesis III, that is, the shortest glide-gap separations will elicit the largest gap-related N1 responses. We also hypothesized that this process will last longer in older adults suggesting an increased distractibility, or a decreased ability to inhibit the processing of task-irrelevant, background auditory events.

2.4.2 Results

Fitting previous results, in younger adults, gaps elicited increasing N1 auditory ERPs with decreasing glide-gap separation. N1 increase was paralleled by an ERP decrease in the P2 interval. In older adults, only a glide-gap separation dependent P2 decrease, but no N1-effect was observable (see Fig. 2.7a). This ERP pattern was likely caused by a fronto-central negative waveform, which was delayed in the older adult group, thus overlapping N1 and P2 in the younger, but overlapping only P2 in the older adult group (see Fig. 2.7b). Because the waveform exhibited a polarity reversal at the mastoids, it was identified as a mismatch

[4] Study IV: **Volosin, M.**, Gaál Zs. A., & Horváth, J. (2017b). Age-related processing delay reveals cause of apparent sensory excitability following auditory stimulation. *Scientific Reports, 7*, 10143.

negativity (MMN). This interpretation also fits previous studies showing that gap-related MMN is delayed in older adults, reflecting an age-related deterioration of fine temporal auditory resolution. These results provide a plausible alternative explanation for the ERP enhancement for sounds following background auditory events.

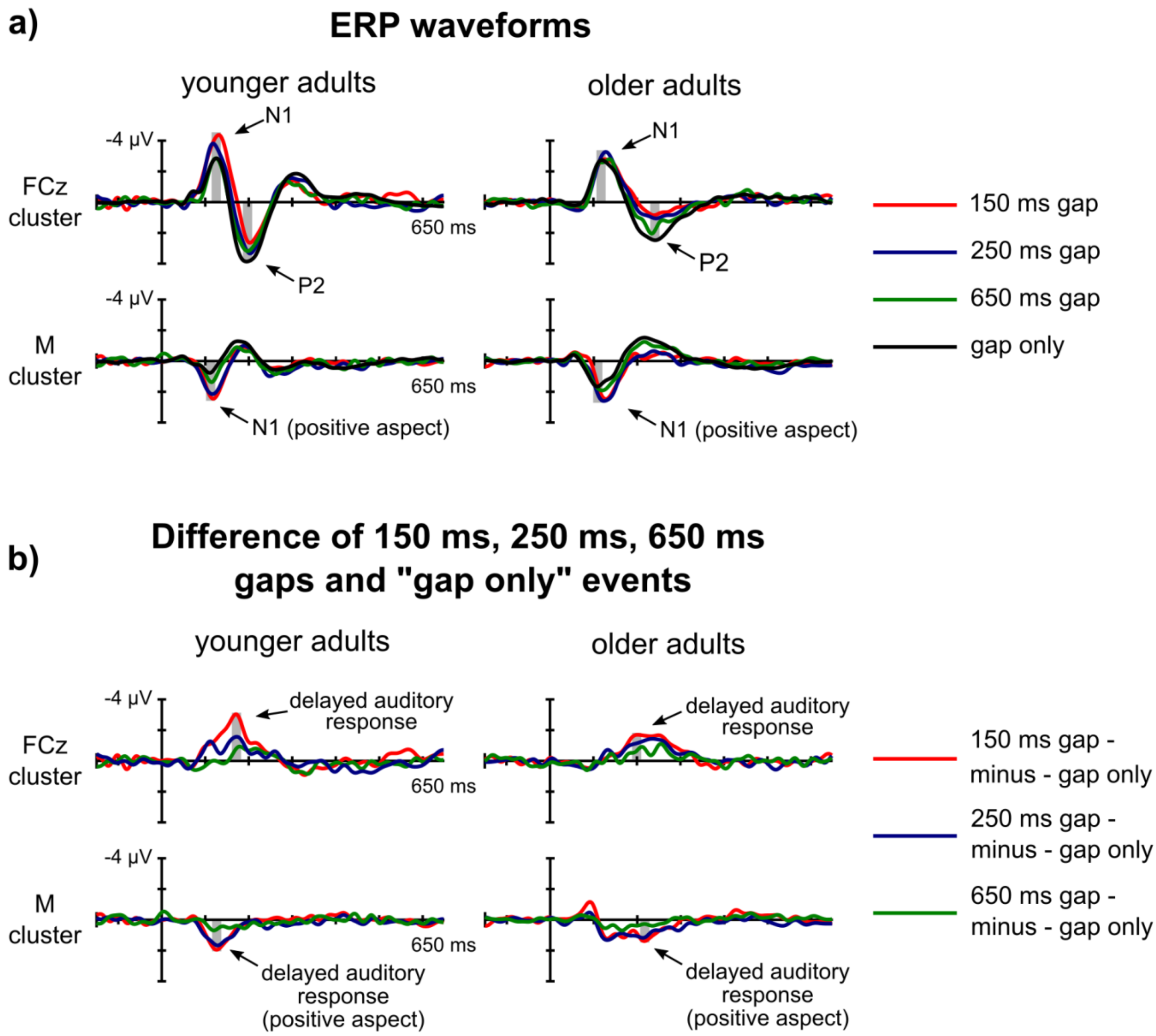

Fig 2.7 Group-mean (younger adults: n=23; older adults: n=23) gap-related ERP waveforms (a) and the difference of 150 ms, 250 ms and 650 ms gaps and “gap only” events (b) measured at the electrode cluster centered on FCz and in the average mastoid signal in the younger and older adult groups. The grey bands indicate the time windows in which the amplitude-related statistical analyses were conducted.

3 DISCUSSION AND CONCLUSIONS

The aim of the present dissertation was to investigate the mechanisms contributing to the balance of attention and distraction and its changes with healthy aging. The present studies support and extend previous results in the literature. Our first two studies (Thesis I-II) demonstrated that explicitly and continuously provided information on the forthcoming stimulus reduces distraction as reflected in the modulation of electrophysiological components. Moreover, we pointed out that the cognitive system is able detect whether otherwise task-irrelevant distracters can predict the occurrence time of a task-relevant event. This process led to enhanced attention and preparation effects to such distracters, suggesting that these events are incorporated into the goal-oriented behavior.

The third and fourth studies of the thesis (Thesis III-IV) aimed to shed light on the duration of the distracted state and its differences with healthy aging. In these studies, the lack of temporal relationship between distracter and target events led to the disruption of the attention set and varying the temporal separation of these two types of events allowed to measure the time needed to recover from distraction. Both studies demonstrated that older adults needed similar amount or more time to re-orient their attention to the original task. In the same time, however, older adults were characterized with deteriorated processing of the fine temporal resolution, which was possible to be compensated with enhanced attention and involvement of additional cognitive sources.

In summary, our studies contribute to the current knowledge on how the cognitive system extracts regularities from the acoustic environment and made a step toward understanding how our brain utilizes this information to perceive the world and control our behavior in an optimal way. We also got closer to explore the duration of the distracted state and its changes with aging. In addition, we found evidence for the declined temporal processing in older age, which can be a major cause of poor speech understanding in noise and which often remains hidden by the common method of audiometry. This condition therefore deserves further attention both when investigating and diagnosing age-related changes in hearing abilities.

4 PUBLICATIONS RELATED TO THE DISSERTATION

Horváth, J., Gaál, Zs. A., & **Volosin, M.** (2017). Sound-offset brain potentials show retained sensory processing, but increased cognitive control in older adults. *Neurobiology of Aging: Age-related Phenomena Neurodegeneration and Neuropathology, 57,* 232-246.

Volosin, M., Gaál Zs. A., & Horváth, J. (2017a). Task-optimal auditory attention set restored as fast in older as in younger adults after distraction. *Biological Psychology, 126,* 71-81.

Volosin, M., Gaál, Zs. A., & Horváth, J. (2017). The duration of distraction during active and passive listening in younger and older adults reflected in N1 amplitudes. Poster presented at *COrtical FEEdback Spring School*, Jena, Germany.

Volosin, M., Gaál Zs. A., & Horváth, J. (2017b). Age-related processing delay reveals cause of apparent sensory excitability following auditory stimulation. *Scientific Reports, 7,* 10143.

Volosin, M., Gaál, Zs. A., & Horváth, J. (2016). No age-differences in recovering from the sensory consequences of auditory distraction. Poster presented at *23rd Annual Meeting of Cognitive Neuroscience Society*, New York, USA.

Volosin, M., Grimm, S., & Horváth, J. (2016). Exploiting temporal predictability: Event-related potential correlates of task-supportive temporal cue processing in auditory distraction. *Brain Research, 1639,* 120-131.

Volosin, M., Grimm, S., & Horváth, J. (2015). Distraction versus task-set change: investigating the functional role of P3a elicited in oddball paradigms. Poster presented at *7th Mismatch Negativity Conference: Error Signals from the Brain*, Leipzig, Germany.

Volosin, M., & Horváth, J. (2014). Knowledge of sequence structure prevents auditory distraction: An ERP study. *International Journal of Psychophysiology, 92,* 93-98.

Volosin, M., & Horváth, J. (2013). Designing distraction-prevention experiments with cue utilization in mind. Poster presented at *1st Leipzig Prediction in Audition Workshop (LPiAW): Attention, Deviance Detection in Auditory Perception*, Leipzig, Germany.

Volosin, M., & Horváth, J. (2013). Preventing distraction in regular tone sequences. Poster presented at *53th Annual Meeting of Society for Psychophysiological Research*, Florence, Italy.

Volosin, M., & Horváth, J. (2013). Preventing attentional distraction in hearing by abstract knowledge about stimulus sequence. Poster presented at *ESCOP 18th Meeting of the European Society for Cognitive Psychology*, Budapest, Hungary.

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